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Impact of fiber properties on yarn strength using spatial REML model for Egyptian cotton

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Abstract: *The purpose of this study is to select the appropriate model of cotton fiber properties and yarn strength using spatial REML method. The fiber quality properties and yarn strength data of 2019 cotton crop season was collected from cotton technical support office, maintenance cotton varieties section, Cotton Research Institute (CRI), Egypt. These data includes six cotton varieties namely; Giza 45, Giza 86, Giza 90, Giza 92, Giza 94 and Giza 95. The monitored cotton fiber quality properties were upper half mean, uniformity index, strength, elongation, micronaire, maturity ratio, reflectance percentage and yellowness degree. These characteristics were divided into eight groups of cotton fiber properties with each other. All cotton fiber properties had high level of spatial dependency except for color attributes; reflectance percentage and yellowness degree, that had no obvious effect. In terms of spatial REML method; the highest appropriate selected models where in third and fourth groups (specific group effect) compared to standard model (no group effect). Selecting the appropriate model depends on the role of the harmony among the used studied selected parameters which fitted to a model. The highest selected models were "uniformity index + fiber strength + elongation" and "upper half mean + uniformity index + elongation + micronaire" according to Wald test, deviance, AICD and BICD. The present investigation included the more affected cotton fiber properties on yarn strength than other different unselected properties. Using spatial REML models is more precise than traditional statistical analyses. Moreover, REML models solve problems that other usual statistical analyses could not solve i.e. missing data, overlapping and unbalanced data.*

Keyword: *Egyptian cotton, spatial REML model, cotton fiber properties.*

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I. Introduction

Egyptian cotton occupies a very distinguished standing compared to other cotton around the world. Cotton production systems are commonly oriented toward yield which is recognized as a major ingredient of profitability. Egyptian cotton characterized by its superior quality which give Egypt a comparative advantages on which comprehensive industry could be developed, that make Egypt was the main producer and exporter of the finnest cotton products. Cotton is the most cash crops and makes a major contribution to Egypt's foreign exchange. Overall, cotton seed is a valuable source of edible oil and cattle feed.

All scientific research centers especially Cotton Research Institute have not step down doing best effort in order to safeguard its world reputation through keeping constant control over various stages of cotton growth.

Reference [4] mentioned that fiber length is the most important fiber character affecting yarn quality. Length and length uniformity have a direct influence on yarn strength, elongation, unevenness, structure and hairiness, as well as on yarn twist performance.

Reference [5] explained all aspects of details from initial to final of micronaire; Micronaire reading is a measure of fiber fineness and related to maturity. Where the rate of air flow through the cylinder is a measure of fiber fineness because coarse fibers have less surface area and air flows through these fibers more easily than fine fibers; then coarse fibers have high mike readings and fine fibers have low mike reading. Fiber fineness is a function of many factors, including the genotype and combination of environmental factors. Reference [28 and 30] detected many investigation of the effect of cotton varieties differing in micronaire value and fiber length on yarn properties so as to contribute a part in improving the raw material utilization. The lower and higher micronaire value affect the yarn regularity negatively while the higher level of fiber length revealed a remarkable improvement in yarn evenness as well as reduction in hairiness.

Cotton fiber strength, according to [6 and 32] is generally measured on fiber bundles, as opposed to single fibers, at either zero-gauge or 1/8" (3.2 mm) gauge. The latter increasingly being measured and accepted worldwide as a better indicator of yarn and fabric strength than former. In terms of Medium Volume instruments, Cotton Classifying System (CCS) provides a reasonably accurate and reliable measure of cotton fiber strength avoiding problems of other High Volume Instrument. Although cottons with good strength usually give fewer problems and neps during processing than weaker cottons, cotton fiber tenacity per se does not play such an important role in processing, except probably in rotor spinning where it can improve spinning performance. Where [14] detected models for yarn engineering provides information about the practical understanding of the generation of the strength of spun yarns.

Generally fiber elongation (extension at break) is measured at the same time with fiber strength, it being determined by genetic and environmental factors. An increase in elongation is associated with an increase in yarn and greige fabric elongation and nep formation. The relationship between yarn elongation and fiber elongation being a function of fiber length and yarn twist and linear density. An increase in fiber elongation can sometimes reduce spinning end-breakage and yarn strength; therefore yarn elongation significantly affects weaving efficiency [24].

Mathematical models may require simplifying assumption to make the mathematics traceable, and hence the prediction errors may be small than before. In contrast, statistical and empirical models are easy to develop in comparison with the mathematical model. However, they require trials under different conditions to obtain the data needed for modeling, and sometimes this data may be affected by measurement errors and process repeatability. Also, they often fail when they are extrapolated to predict properties outside the range within which the data was obtained [33].

The purpose of statistics is to describe and predict information. A statistical model is a combination of inferences based on collected data and population understanding used to predict information in an idealized form. More generally, statistical models are part of the foundation of statistical inference [23].

Mathematical models have their basis in applied physics and derived from first principles. They provide a better understanding of the complex interrelationships of the different models of cotton fiber properties that influence yarn properties. Initially, a Parameter in a model reveals and quantifies the trend and the aim of a model. Generally, is any characteristic that can help in defining or classifying a particular problem. That is, a parameter is an element of a system that is useful, or critical, when identifying the system, or when evaluating its performance, status, condition, etc. [24, 26, 31 and 35].

Basically building models to understand with estimating how reality will or did function and to take better decisions based on the outputs. Statistics or not, human has probably doing modeling in all aspects of life and sciences [11, 20 and 34].

Model building in terms of choosing different cotton fiber properties- such as length, strength, fineness and color properties-is one of those skills in statistics that is difficult to teach. It is hard to lay out the steps, because at each step, researcher has to evaluate the situation and make decisions on the next step. So, the purpose of this study is modeling the relationships among the cotton fiber properties and yarn strength using one type of spatial models; that is spatial REML model. All details of building models explained by [9, 13, 21, 27, 29 and 34].

II. Materials And Methods

The present investigation includes data base of 2019 crop season from cotton technical support office. The source of these data base is maintenance cotton varieties section in Cotton Research Institute (CRI) at Agricultural Research Center (ARC).

These data includes six cotton varieties namely; Giza 45, Giza 86, Giza 90, Giza 92, Giza 94 and Giza 95.

Measurements of cotton fiber properties factors are performed by High Volume Instrument (HVI) ASTM [1] as follows:

- Upper Half Mean (UHM) is the average of the longer one-half of the fibers.
- Uniformity index (UI %) is the ratio between upper half length and mean length.
- Strength (FS) is the force in grams required to break a bundle of fibers on tex.
- Elongation (E %) is an important cotton fiber property that directly affects yarn elongation and work-to-break values.
- Micronaire value (Mike) is a measure of fiber fineness and maturity.
- Maturity ratio (MR) is the index of development of the fiber.
- Reflectance percentage (Rd %) indicates how bright or dull a sample is.
- Yellowness degree (+b) indicates the degree of color pigmentation.

Cotton fiber samples were spun at 3.6 twist factor for Ne 60 count. Yarn strength (Ys) in terms of Lea product in pounds count was measured by the Good Brand Lea tester.

Statistical analyses and methods:

Descriptive statistics analyses were computed among characters studied according to the methods described by [36].

References [16, 31 and 33] proposed spatial models of Restricted Maximum Likelihood (REML) to improve the precision of data results. The outcome of cotton fiber properties were assumed to influence directly by the treatment (the cotton genotypes) applied to it and indirectly by treatments applied to each neighboring plot. A model taking into account trend effect and interplot competition.

The model can be written as follows:
$Y = B\pi + T\alpha + RT\beta + \varepsilon + e$
Where; Y is an n-vector of plot outcome.
π is a b-vector of block effects within incidence matrix B.
T is the corresponding design matrix.
α is a t-vector of treatment effects.
R is the neighbor incidence matrix.
β is a t-vector of competition.
ε is an n-vector of interplot competition.
e is an n-vector whose elements represent local error.
For each spatial REML model, alternative models (specific group effect) concerning cotton fiber properties are compared with the standard model (no group effect). Using Genstat package, estimated parameters for models; wald test, deviance (DV), Chi square (χ^2) tester, Akaike information criterion deviance (AICD) and Bayesian information criterion deviance (BICD).
1- Wald test is a way of testing the significance of particular explanatory variables (cotton genotypes) in a statistical model. [19].
2- Deviance is a measure of lack of fit between alternative models and the standard model; the larger deviance value the poorer fit of alternative model.
Deviance= -2 log likelihood (standard or alternative models).
3- Akaike information criterion deviance (AICD) and Bayesian or Schwarz information criterion deviance (BICD) are both methods of assessing model fit penalized for the number of estimated parameter. The optimum model is selected based on minimum AICD and BICD according to [2 and 37].
AICD = Deviance + 2 q
Where; q = variance covariance parameters which is not included in deviance.
BICD= Deviance + 2 Ln (N) q
Where; N is the number of recorded measurements.
Based on the previous parameter estimates computed for spatial REML models; the best model could be recognized compared to the standard model estimates.
Using eight groups for alternative models; first group (contained of cotton fiber properties as per se), second group (contained of two cotton properties), third group (contained of three cotton properties), fourth group (contained of four cotton properties), fifth group (contained of five cotton properties, sixth group (contained of six cotton properties), seventh group (contained of seven cotton properties) and finally eighth group; with all calculated combinations for each group.
A gain in precision of different statistical procedures could be detected according to C.V. for traditional design estimates and R.D. for spatial REML models estimates [7 and 31].
Genstat (2000) programme [15] was also used for all previous statistical analyses.

III. Results

The descriptive statistics of upper half mean (UHM), uniformity index (UI%), fiber strength (FS), elongation (E%), micronaire (Mike), maturity ratio (MR), reflectance percentage (Rd%), yellowness degree (+b) and yarn strength (YS) for Giza 45, Giza 86, Giza 90, Giza 92, Giza 94 and Giza 95 are shown in Table 1.

Table 1: Descriptive statistics for Giza 45, Giza 86, Giza 90, Giza 92, Giza 94 and Giza 95.

Variety		UHM	UI%	FS	E%	Mike	MR	Rd%	+b	YS
Giza 45	Min.	34.20	84.80	41.50	6.00	2.00	0.86	71.30	7.30	2320
	Max.	36.10	87.50	47.30	6.50	3.10	0.90	77.00	9.60	2800
	Mean	35.18	85.85	44.78	6.33	2.89	0.88	73.75	8.18	2552
	C.V.	1.44	0.88	3.86	3.35	9.34	1.17	2.08	6.60	6.34
Giza 86	Min.	30.60	84.00	43.00	7.00	4.40	0.94	71.70	7.70	1860
	Max.	32.70	87.20	47.00	7.50	4.60	0.96	77.30	8.60	2400
	Mean	31.89	85.84	44.84	7.28	4.50	0.95	73.85	8.17	2184
	C.V.	1.78	1.19	2.84	2.09	1.46	0.62	1.84	3.44	6.61
Giza 90	Min.	29.50	84.30	38.40	8.00	3.90	0.90	63.50	11.20	1830
	Max.	30.90	86.50	40.80	8.50	4.10	0.92	76.00	12.80	2190
	Mean	30.19	85.51	40.09	8.34	4.03	0.91	66.62	11.84	1978
	C.V.	1.22	0.76	1.65	1.80	1.53	0.92	4.22	4.26	4.79
Giza 92	Min.	31.60	84.80	44.00	6.00	3.10	0.89	73.00	7.10	2040
	Max.	34.40	88.00	50.00	6.80	3.40	0.94	78.50	8.30	2800
	Mean	33.04	86.31	46.91	6.28	3.23	0.92	76.11	7.81	2677
	C.V.	2.29	1.06	3.43	3.86	3.20	1.86	1.77	3.96	6.98
Giza 94	Min.	32.70	84.2	41.30	7.00	3.60	0.92	67.10	7.30	2040
	Max.	35.15	87.3	45.60	7.50	4.80	0.95	79.90	10.90	2580

	Mean	33.78	86.09	44.55	7.40	4.14	0.94	77.08	7.96	2244
	C.V.	2.24	1.04	2.45	1.98	6.57	0.98	3.89	10.52	6.69
Giza 95	Min.	29.60	83.70	40.00	8.00	3.90	0.90	66.70	10.60	1830
	Max.	31.90	87.30	40.80	8.60	4.30	0.95	70.80	12.60	2350
	Mean	31.02	85.69	40.40	8.32	4.17	0.92	67.67	11.47	2179
	C.V.	2.22	1.28	0.62	2.14	2.82	1.55	1.62	4.68	5.823

Min., Max. and C.V. refer to minimum, maximum and coefficient of variation, respectively.

Giza 45 had the highest value of UHM with 35.18 meanwhile Giza 92 had the highest value of UI, FS and YS with 86.31, 46.91 and 2677, respectively.

The least value of C.V. for FS and MR in Giza 95 and Giza 86, respectively. Especially coefficient of variation was detected as the precision of cotton fiber properties as a simple descriptive statistic which can be the indicator comparison between traditional and untraditional analyses.

The model is a mathematical model that embodies a set of statistical assumptions concerning the generation of data. A statistical model for cotton is usually specified as a relationship between one or more cotton fiber properties. Using spatial REML models analyses describe more accurate the different layers of variation and provide more appropriate and correct analyses [18, 25 and 22]. The purpose of using spatial REML is to provide a more accurate method than traditional statistical analyses which solve data problems.

In spatial REML models, there is one standard model (no group effect) is the main model to all alternative models (specific group effect).

In terms of comparing alternative models with standard model using parameter estimates; Wald test, F-test, Deviance (DV), Akaike information criterion deviance (AICD) and Bayesian information criterion deviance (BICD).

The explanatory variables (cotton varieties) or group of explanatory variables (five cotton genotypes) their wald test were significant. Then it would be concluded that the parameters associated with genotypes are not zero, so the cotton varieties should be included in the model. If the wald test is not significant then these studied cotton genotypes can be omitted from the model. Therefore using any cotton variety give the same trend without differences and that is not reasonable in interpretation of data. Therefore, it uses in wide scales of imported genotypes. All interpretation of that point argued by [1].

Deviance (DV) plays the role in REML that variance plays in analysis of variance (ANOVA). The deviance can be regarded as a measure of lack of fit between alternatives and standard model. In general, the larger the deviance, the poorer the fit of the data [12]. The change in deviance is distributed approximately as the chi square (χ^2) with effective degrees of freedom (edf) equal to the change in individual edf between the two models. Large values of (χ^2) statistic are taken as evidence that the null hypothis is implausible [8 and 33].

Akaike information criterion deviance (AICD) and Bayesian information criterion deviance (BICD) express according to deviance, was used to choose among spatial REML models. Where a lower value of AICD and BICD indicates a better model [23].

Therefore, select the appropriate model depends on the harmony among high and significant value of wald test, low and significant value of deviance, low values of akaike information criterion deviance and bayesian information criterion deviance compared to these parameters of standard model.

First group included individual cotton fiber properties; i.e. upper half mean (UHM), uniformity index (UI %), fiber strength (FS), elongation (E %), micronaire (Mike), maturity (MR), reflectance percentage (Rd %) and yellowness degree (+b) as shown in Table (2).

Table 2: Parameter estimates of first group.

Parameters	**Wald test**	**F-test**	**DV**	χ^2	**AICD**	**BICD**	**R.D.**
Standard model	236.75	47.35	938.55	0	940.55	942.98	6.39
UHM	245.82	48.86	938.44	0.11*	939.44	940.30	3.71
UI%	236.87	47.34	938.54	0.01*	940.54	940.40	4.31
FS	215.38	42.72	937.45	1.1**	939.45	940.31	3.21
E%	467.34	70.34	936.66	1.89**	938.01	939.52	2.17
Mike	236.74	47.35	938.55	0	942.55	947.41	6.00
MR	309.61	58.04	937.69	0.86*	940.69	941.55	4.42
Rd%	200.45	39.30	939.52	0.97*	940.52	944.39	6.51
+b	205.61	40.78	939.84	1.29*	944.84	945.70	8.92

The wald test for cotton fiber properties whether standard model or alternative models can tell which model of cotton fiber properties are contributing more significant than others [10].

The values of wald test for yellowness degree (+b) and reflectance percentage (Rd%) are 205.61 and (200.45), F-test (40.78) and (39.30), deviance 939.84 and 939.52, AICD (944.84) and (940.52) and BICD (945.70) and (944.39), respectively so it is no use to select alternative models of reflectance percentage or yellowness degree, that was proved before by [17 and 20]. That expected as color attributes have no impact on yarn properties. The integration of parameters of properties for each one; highest value of wald test (467. 34), highest value of F-test (70.34), lowest value of deviance with highly significant, lowest value of AICD (938.01) and BICD (939.52) compared to standard model. The elongation is the first selected alternative then fiber strength, upper half mean, uniformity index, maturity, micronaire followed by reflectance percentage and yellowness degree.

Relative distance (R.D.) evaluated alternatives compared to coefficient of variation (C.V.) in traditional statistical analyses. The best alterative model was for elongation with the lowest C.V. (2.17) then strength (3.21), upper half mean (3.71), uniformity index (4.31), maturity (4.42), micronaire (6.00) followed by reflectance (6.51) and yellowness (8.92). Then spatial REML model was in the same trend with coefficient of variation (C.V.).

Second group included two cotton fiber properties in terms of Table (3), first sub-group concluded the same related properties; (UHM and UI), (FS and E %), (Mike and MR) and (Rd % and +b), meanwhile the second sub-group included all combinations of two properties; Table (3) concluded the five highest two properties only.

Table 3: Parameter estimates of second group.

Sub-group	Parameters	Wald test	F-test	DV	χ^2	AICD	BICD	R.D.
First	Standard model	236.75	47.35	938.55	0	940.55	942.98	6.39
	UHM+UI%	246.16	48.90	932.42	6.13^{**}	935.42	938.71	4.09
	FS+ E%	346.72	62.62	925.15	13.4^{**}	933.15	935.44	3.37
	Mike+ MR	236.74	47.35	935.55	3.4^{**}	939.11	941.84	4.39
	Rd%+(+b)	201.05	39.77	938.68	0.13^{*}	955.68	942.97	9.21
Second	UHM+ E%	468.65	74.81	920.63	17.92^{**}	925.63	930.92	3.09
	UHM + MR	343.86	68.77	925.49	13.06^{**}	928.49	931.78	3.84
	UI% + MR	318.28	58.70	929.63	8.92^{**}	930.63	938.92	4.44
	MR + E%	313.69	57.78	930.69	7.86^{**}	937.69	940.98	5.17
	FS + MR	275.10	52.17	934.74	3.81^{**}	940.00	945.03	5.69

In terms of the used parameters for first sub-group; the more effective cotton fiber properties for yarn strength were FS with E% followed by UHM with UI% then Mike with MR and eventually color attributes sub-group has no effect. Meanwhile second sub-group were obviously more visible effect for sub-groups of the highest five models; "UHM + E%", "UHM + MR", "UI + MR", "MR + E%" followed by "FS + MR". According to previous results length properties were the premier of other studied properties then followed by strength properties and maturity. The same trends of fiber cotton models were detected using R.D. values with standard model. Length and strength properties play the crucial role compared to other cotton fiber properties using parameters spatial REML estimates.

Third and fourth groups detected in Table (4) for spatial REML parameters for all studied cotton varieties.

Table 4: The highest four models estimates of third and fourth groups.

Parameters	Wald test	F-test	DV	χ^2	AICD	BICD	R.D.
Standard model	236.75	47.35	938.55	0	940.55	942.98	6.39
UI+FS+E%	420.09	64.13	932.86	5.69^{**}	935.86	937.59	2.34
UHM+UI+E%	240.41	47.56	933.37	5.18^{**}	936.37	938.10	2.89
UHM+ E %+Mike	236.74	47.35	933.55	5.00^{**}	938.55	939.27	3.88
UHM+UI+Mike	232.44	46.30	934.52	4.03^{**}	939.52	941.25	3.89
UHM+UI+ E%+Mike	236.74	47.35	938.55	0	938.81	939.77	3.31
UHM+UI+ E%+MR	232.44	46.30	936.52	2.03^{**}	939.52	940.68	3.39
UI+FS+ E%+MR	215.19	42.65	937.44	1.11^{*}	940.44	941.60	4.25
UI+FS+ E%+Mike	203.61	40.27	937.75	0.80^{*}	940.52	942.00	4.81

In third group; the highest selected appropriate models was "UI + FS + E %", "UHM + UI + E %", "UHM + E % + Mike" and the last selected model was for "UHM + UI + Mike" with gradually decreased in coefficient of variation (C.V.), respectively. According to fourth group; in spite of the equality of deviance for "UHM + UI + E % +Mike" with standard model, this model was the highest selected one according to other parameters followed by "UHM + UI + E % + MR", "UI + FS + E % + MR" and "UI + FS + E % + Mike".

Table (5) detected differences among alternative models compared to standard model with parameter estimates for each model. In fifth group the selected alternative models were "UHM + UI + E% + Mike + MR", "UHM + FS + E% + Mike + MR", "UI + FS + E % + Mike + MR" and "UHM + UI + FS + Mike + MR".

Table 5: The highest four models estimates of fifth and sixth groups.

Parameters	Wald test	F-test	DV	χ^2	AICD	BICD	R.D.
Standard model	236.75	47.35	938.55	0	940.55	942.98	6.39
UHM+UI+E%+Mike+MR	232.44	46.30	934.52	4.03**	939.52	940.11	3.39
UHM+FS+E%+Mike+MR	215.38	42.72	937.45	1.10**	939.99	941.04	4.17
UI+FS+E%+Mike+MR	211.18	41.80	934.74	3.81**	940.00	941.32	4.25
UHM+UI+FS +Mike+MR	203.64	40.15	929.77	8.78**	933.21	935.36	4.25
UHM+UI+FS + E%+Mike+MR	215.19	42.16	937.44	1.11*	938.44	939.46	4.00
UHM+UI+FS + E%+Mike++b	211.17	41.80	934.74	3.81**	937.74	941.79	5.21
UHM+UI+FS + E%+Mike+Rd%	211.00	41.63	936.74	1.81*	939.74	942.75	5.33
UHM+UI+FS + E%+MR++b	204.36	40.40	939.72	1.17*	940.00	942.76	5.41

Meanwhile, the selected alternative models in sixth group were "UHM + UI + FS + E% + Mike + MR", "UHM + UI + FS + E% + Mike + (+b)", "UHM + UI + FS + E% + Mike + Rd%" and "UHM + UI + FS + E% + MR + (+b)".

Table (6) elaborated the highest selected alternative models with REML parameters but there is different in parameters values compared to all above previous models compared to standard model. In seventh group, the highest four alternative models were "UHM + UI + FS + E% + Mike + MR + Rd", "UHM + UI + FS + E% + Mike + MR + (+b)", "UHM + UI + FS + E% + Mike + Rd + (+b)" and "UHM + UI + FS + E% + MR + Rd% + (+b)".

Table 6: Parameter estimates of seventh and eighth groups.

Parameters	**Wald test**	**F-test**	**DV**	χ^2	**AICD**	**BICD**	**R.D.**
Standard model	236.75	47.35	938.55	0	940.55	942.98	6.39
UHM+UI+FS+E%+Mike+MR+Rd%	217.31	42.70	936.56	1.99	939.56	940.01	5.86
UHM+UI+FS+E%+Mike+MR++b	210.99	41.63	936.74	1.81	940.74	941.18	5.88
UHM+UI+FS+E%+Mike+ Rd%++b	204.36	40.27	938.05	0.50	940.77	940.58	5.90
UHM+UI+FS+E%+ MR+Rd%++b	201.78	39.01	939.55	1.00	941.98	943.55	5.99
UHM+UI+FS+E%+Mike+MR+Rd%++b	213.91	42.78	938.36	0.19	942.36	943.23	5.12

A model that takes more than four group parameters indicates problems; the function is doing too much as it should be where deviance, AICD and BICD do not give the premier asymptotes as do in the three and four groups. In addition, color properties do not need to create model that includes these parameters in terms of parameter estimated.

Eventually, the model with three and four predictors fits significantly better than the model with only one, two, five, six, seven and eight Predictors comparing with each other. Although all spatial alternative REML models of cotton fiber properties were more precise than standard model or traditional statistical analyses.

IV. Conclusion

Spatial restricted maximum likelihood (REML) is a term that may relate to a single characteristic or a system of combined characteristics, such as collaboration using shared models developed to common standards, as well as activities including model co-ordination and interface management. Therefore, appropriate traditional analyses need to be supplement with appropriate untraditional statistical methods. Therefore, spatial REML models are accounting variability in field or laboratory experiments. And that could be useful for plant breeder, agronomist or fiber technological laboratories, and spinning process which can come over all problems. A spatial REML model is proposed for incorporating both trend effect and interplot competition. Therefore, spatial REML analysis describes more accurately the different layers of variation and it provides more appropriate and correct analysis for any number of cotton fiber properties (random parameters) where the variance changes across the levels of a factor (fixed parameter). Length (upper mean length and uniformity index) and fiber strength and elongation have more effect on yarn strength than other different unselected properties in alternative models. Spatial REML models are more precise than traditional statistical analyses. Moreover, REML models solve problems that other usual statistical analyses could not solve, i.e. missing data, overlapping and unbalanced data.

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